EFFECT OF SURFACE TREATMENT ON FATIGUE LIFE OF PISTON

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Report submitted in partial fulfillment of the requirements
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Dedicated to my beloved

Parents and Siblings

For their endless support in term of motivation,

Supportive and caring as well throughout the whole project

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ABSTRACT

Prediction of fatigue life on piston for four stroke engine using variable amplitude loading is presented. The piston is the crucial part of the internal combustion engine. The objectives of this project are to predict fatigue life of piston for four stroke engine using strain-life method, to identify the critical locations, to investigate the effect of mean stress and to optimize the component material. The structural and finite element modeling has been performed using a computer aided design and finite element analysis software package. The finite element model of component then analyzed using the Strain method approach. Finally, the stress-strain state of component obtained previously will be use as input for the fatigue life. The effected mean stress and materials optimize was also too investigated. The failure of piston can result in devastating damage to the engine including all the components from a tiny screw till a huge belting system. Life of piston needs to be improved to prevent from any unpleasant problems. The results of the analysis showed that there are no serious failure occurs at the part of the piston. However it is observed that the minimum predicted life at the critical location is $10^{2.38e-7}$ under variable amplitude loading for strain-life approach. The optimization results showed 7075 T6 aluminum alloy that is the most superior material among the others.

ABSTRAK

Ramalan jangka hayat bagi piston enjin empat lejang dipersembahkan. Objektif untuk projek ini ialah untuk meramal jangka hayat bagi piston untuk enjin empat lejang, untuk mengenal pasti lokasi kritikal yang terdapat pada piston, untuk menyiasat hubungan dan kesan ketegangan purata daripada jangka hayat keterikan dan untuk mengoptimumkan pemilihan bahan. Model struktur dan elemen finiti telah dibuat menggunakan perisisan lukisan secara berkomputer dan analisis elemen finiti. Model bagi elemen finiti tersebut kemudian dianalisa menggunakan pendekatan *Ketegangan*. Akhir sekali, keterikan dan ketegasan bagi komponen tersebut yang telah dicapai akan digunakan sebagai input untuk jangka hayat lesu. Kesan keterikan purata dan bahan yang optimum akan diperiksa. Piston ialah bahagian yang paling penting sekali di dalam sesebuah enjin. Kegagalan piston untuk berfungsi dengan baik akan menyebabkan kerosakan teruk kepada enjin termasuklah semua komponen samada dari sekecil bahagian seperti skru hinggalah kepada system enjin. Jangka hayat piston perlulah diperbaiki untuk mengelakkan daripada berlakunya masalah-masalah yang tidak diingini. Keputusan analisa menunjukkan tiada kegagalan yang serius berlaku pada mana-mana bahagian piston. Walau bagaimana pun daripada pemerhatian menunjukkan jangka hayat paling minima di lokasi kritikal ialah $10^{2.38e-7}$ dibawah tindakan amplitud yang berubah untuk hayat ketegangan. Akhir sekali, bahan yang terbaik hasil daripada analisa ialah aluminum alloy 7075 T6 berbanding dengan baha-bahan lain.

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LIST OF SYMBOLS

C_p	Specific heat of constant pressure
C_v	Specific heat of constant volume
N	Engine speed
P	Pressure
P	Power
Q_{HHV}	Higher heating value
Q_{LHV}	Lower heating value
R	Gas constant
T	Temperature
T_o	Standard temperature
V	Cylinder volume
V_{BDC}	Cylinder volume at bottom dead center
V_d	Displacement volume
V_{TDC}	Cylinder volume at top dead center
W	Work
k	Ratio of specific heats
m	Mass
m_a	Mass of air
m_f	Mass of fuel
m_m	Mass of gas mixture
n_r	Number of crank revolutions
q	Heat transfer per unit mass
r_c	Compression ratio

v	Specific volume
v_{BDC}	Specific volume at bottom dead center
v_{TDC}	Specific volume at top dead center
w	Specific work
η_t	Thermal efficiency
ρ	Density

CHAPTER 1

INTRODUCTION

1.1 Project Background

Every engineering product is not just made or is made, but it must follow the sequence step to achieve good product. The steps are design, manufacture and lastly perform specific function to human needs. Design engineering is actually a decision-making process to developed or improved product at a reasonable cost. Parameters included in such an analysis are:

- Geometry and dimensions of different parts,
- Types of materials used in manufacturing and their specifications,
- Fabrication and assembling techniques
- Service conditions.

In real life to developed a product, high cost is need because the product must follow a few testing using a few materials and a few design to get a good product. Because of that, engineers nowadays use a modern computational approach based on finite element analysis to reduce the testing cost. This paper describes the finite element analysis techniques to predict the fatigue life and identify the critical locations of the piston that have been treatment using a few surface treatment processes. This surface treatment method is important to increased loads (mechanical, thermal, etc.), longer lifetime, weight reduction, friction reduction, and corrosion resistance are demanded for modern automotive systems.

The finite element modeling and analysis has been performed using a computer-aided design and a finite element analysis software package, and the fatigue life prediction was carried out using finite element based fatigue life prediction codes. The results showed the contour plots of the fatigue life histogram and damage histogram at the most critical location.

1.2 Problem Statement

Nowadays, manufacturers are utilizing different surface treatments to enhance the surface properties of engineering materials so this problem is to increases the fatigue life of piston are demanded for modern automotive systems.

1.3 Objectives of Project

The objectives of this project are as follows;

i. To predict fatigue life of piston for four stroke engine using strain-life method and to identify critical locations
ii. To investigate the effect of surface treatment
iii. To optimize the material of the component

1.4 Scopes of Project

To fulfill this project, some jobs are including such as:

- Structural modeling of piston by using SolidWork software
- Finite Element modeling and Analysis
- Fatigue Analysis
    1. Strain-life method
    2. Variable amplitude loading
    3. Surface treatment
- Optimization

1.5 Overview of Report

Chapter 1 is explanation about introduction of the project. In this chapter also include the objectives and scope of the project. Chapter 2 discusses on the literature review of piston, type of surface treatment and Strain method. Chapter 3 provides the project methodology for analysis the fatigue life of the piston. The methodology consists of piston model using SolidWork software, and all the analysis included finite element analysis, fatigue analysis and optimization using MSC.Patran and MSC.Nastran. Chapter 4 discuss about the fatigue life of piston and optimization of the results. Finally, Chapter 5 concludes the result of analysis. The recommendation is provided for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides the review of the past research selected to the fatigue Analysis, finite element analysis and surface treatment include nitriding, cold rolled and shot peened on the fatigue life. The past research effort can be properly guided to justify the scope and direction of the present effort

2.2 Piston

Engine pistons are one of the most complex components among all automotive or other industry field components. The engine can be called the heart of a car and the piston may be considered the most important part of an engine. There are lots of research works proposing, for engine pistons, new geometries, materials and manufacturing techniques, and this evolution has undergone with a continuous improvement over the last decades and required thorough examination of the smallest details.

Notwithstanding all these studies, there are a huge number of damaged pistons. Damage mechanisms have different origins and are mainly wearing, temperature, and fatigue related. Among the fatigue damages, thermal fatigue and mechanical fatigue, either at room or at high temperature, play a prominent role.

This work is concerned only with the analysis of fatigue-damaged pistons. Pistons from petrol and diesel engines, from automobiles, motorcycles and trains will be analyzed. Damages initiated at the crown, ring grooves, pinholes and skirt are assessed. A compendium of case studies of fatigue-damaged pistons is presented. An analysis of both thermal fatigue and mechanical fatigue damages is presented and analyzed in this work.

A linear static stress analysis, using finite element analysis software Package MSC.PATRAN /MSC.NASTRAN, is used to determine the stress distribution during the combustion. Stresses at the piston crown and pinholes, as well as stresses at the grooves and skirt as a function of land clearances are also presented. A fractographic study is carried out in order to confirm crack initiation sites.

Figure 2.1: Piston

2.3 Piston Material

The materials that piston are made from should meet certain requirement such as good cast ability: high hot strength; high strength to mass ratio; good resistance to surface abrasion, to reduce skirt and ring-groove wear; good thermal conductivity, to keep down piston temperatures; and a relatively low thermal expansion, so that the piston to cylinder clearance can be kept to a minimum. Some of these properties will now be considered.

For many years the eutectic Al–Si alloy has been used for pistons (because only aluminum pistons have been assessed in this work only aluminum alloys will be presented). With increased piston temperatures, the need for equal or improved fatigue strength could no longer be satisfied. New alloys with increased Si content and Cu content, and other alloying elements, have been proved be satisfactory to the new requirements. Use of metal matrix composites is already in use and also under investigation.

For the future, additional improvements of the materials properties may be expected. New technologies are also promising such as PM since its components exhibit excellent strength properties. PM has a significant potential for further development. However, these changes must take into account that an efficient heat transport from the piston to the liner and to the oil is needed. Other technologies and die-casting processes are also being developed.

The development of new materials and processing technologies with improved high temperature mechanical and fatigue performance would help solving the different fatigue damages identified in this work.

Table 2.1: Mechanical Properties of Aluminum Alloys at Room Temperature

Materials properties For Aluminum Alloy	Value
Young's modulus, E, GPa	68 - 79
Ultimate tensile strength, S_u , MPa	90 - 600
Tensile Yield Strength	35 - 550
Elongation in 50 mm	0.065

2.3.1 Aluminum Alloy

The important factors in Aluminum Alloy are their high strength-to-weight ratio, their resistance to corrosion by many chemicals, their high thermal and electrical conductivity, their nontoxicity, reflectivity, appearance, and their ease of formability and of machinability; they are also nonmagnetic.

Aluminum Alloy are available as mill products, that is, as wrought products made into various shapes by rolling, extrusion, drawing, forging and form for power-metallurgy applications. Techniques have been developed whereby most aluminum alloys can be machined, formed and welded with relative ease.

2.4 Fatigue Life

Fatigue is a localized damage process of a component produced by cyclic loading. It is the result of the cumulative process consisting of crack initiation, propagation, and final fracture of a component. During cyclic loading, localized plastic deformation induces permanent damage to the component and a crack develops. As the component experiences an increasing number of loading cycles, the length of the crack (damage) increases. After a certain number of cycles, the crack will cause the component to fail (separate). The required inputs for the fatigue analysis process are shown in Fig. 2.2.

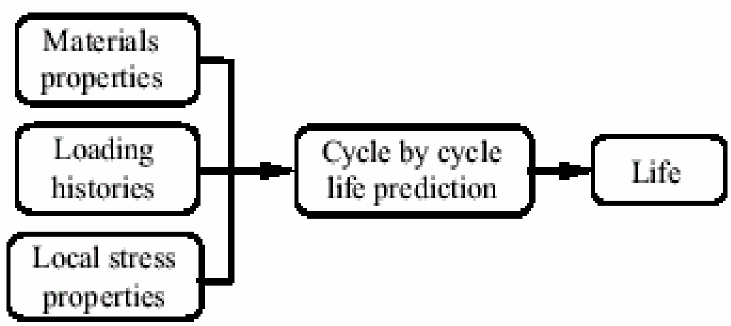

Figure 2.2: Schematic Diagram of Fatigue Life Estimation

2.5 Strain-Life

The local strain-life method was developed in late 1950s and has been shown to be more effective in predicting the fatigue life of a component. The local strain-life method is based on the assumption that the life spent on crack nucleation and small crack growth of a notched component can be approximated by a smooth laboratory specimen under the same cyclic deformation at the crack initiation site.

This concept used to determine the fatigue life at a point in a cyclically loaded component if the relationship between the localized strain in the specimen and fatigue life is known. This relationship is typically represented as a curve of strain versus fatigue life and is generated by conducting strain-controlled axial fatigue tests on smooth, polished specimens of the material. Strain-controlled axial fatigue testing is recommended because the material at stress concentrations and notches in a component may be under cyclic plastic deformation even when the bulk of the component behaves elastically during cyclic loading.

The local strain-life method can be used proactively for a component during early design stages. Fatigue life estimates may be made for various potential design geometries and manufacturing process prior to the existence of any actual component provided the material properties are available. The local strain-life approach is preferred if the load history is irregular or random and where the mean stress and load sequence effects are thought to be importance. This method also provides a rational approach to differentiate the high-cycle fatigue and the low-cycle fatigue regimes and to include the local notch plasticity and mean stress effect on fatigue life.

2.6 Surface Treatment

Surface treatments used in daily manufacturing of parts for the automotive industry are selected to serve functional and decorative requirements achieved by mass production. Increased loads (mechanical, thermal, etc.), longer lifetime, weight reduction, friction reduction, and corrosion resistance are demanded for modern automotive systems. Within the last decade, improved and new deposition techniques were developed in PVD, PECVD, thermochemical heat treatment and thermal spraying.